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COMBUSTION - NOISE AND VIBRATION RESEARCH PROJECT

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by

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ABSTRACT

Noise from mining vehicles has a most pervasive influence on the underground environment. The most used machines are the load-haul-dump (LHD) vehicles.

As a result of fuel becoming scarce and more expensive, diesel engines may be required to run on fuels with low cetane numbers. A reduction from 53.3 CN to 36.3 CN produced a 4.5 dBA increase in combustion noise from a typical truck engine. If the diesel engine is to become more widely used in mines to propel vehicles, there is a need to make noise and vibration from diesel engines more acceptable, apart from the requirements to reduce overall levels to bring the total vehicle noise below limits submitted in legislation.

The noise regulations used in Canada, excepting British Columbia, are those adopted by the OSHA. British Columbia used International Standard R1999.

Noise is radiated from external surfaces of the engine as they vibrate in response to the forces developed within the engine. The noise radiated by the engine surfaces originates from combustion, piston and timing gear impacts.

All research and measurements will be performed in the laboratory (indoors and outdoors) and underground in the mine.

The most difficult problem is to reduce the engine surface noise. The engine noise requires a reduction of more than 10 dBA, to meet OSHA requirements. The noise and vibration are in causal connection. In general

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there are three basic ways to reduce combustion noise:

- reduce ignition delay period;
- reduce fuel injected in the ignition delay period; and
- restrict air/fuel mixing during the delay period.

Any changes made to combustion system to reduce noise will affect other aspects of combustion system performance - smoke, fuel consumption and emissions of nitrogen oxides and unburnt hydrocarbons. The research will be very difficult.

Total investment in noise and vibration instruments is $122,334.00.

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INTRODUCTION

NUISANCE

Noise from mining vehicles has a most pervasive influence on the underground environment. The results of a survey of noise in mines showed that noise from mining traffic disturbed far more workers than noise from any other source in the mines. The most used machines are the load-haul-dump (LHD) vehicle. For the most part the vehicles used for underground mining operations are powered by engines with more than 130 hp. The machine, as a source, does not produce a continuous noise. The noise varies from one day to the next and therefore from one site to the next. The operators and bystanders are exposed to these variable sound sources.

In order to illustrate the effects of noise exposure index of different machines, Table 1 was completed.

NOISE CONTROL THROUGH COMBUSTION EFFICIENCY

As a result of fuel becoming scarce and more expensive, diesel engines may be required to run on fuels with low cetane numbers. A reduction from 53.3 CN to 36.3 CN produced a 4.5 dBA increase in combustion noise from a typical truck enginer (1). Less extreme reductions to 40 or 45 CN are likely to increase combustion noise by 2 to 3 dBA. These increases in sound level may not appear to be very significant, but the impulsive character in sound emitted will be accentuated. Investigations into complaints of noise from industrial premises show that most complaints concern noise with strong impulsive or tonal characteristics. It seems likely, therefore, that degradation of the fuel will cause more disturbance than the increase in noise level would seem to indicate.

If the diesel engine is to become more widely used in mines to

Table 1 - Noise of different vehicles

No.	Vehicle Type and Manufacturer	L_{eq}* (dBA)	Note
1	MTT-420 Teletram Wagner	100.5	175 hp
2	ST5A Scooptram Wagner	100.5	175 hp
3	ST4A Scooptram Wagner	105.6	145 hp
4	ST2B Scooptram Wagner	98	78 hp
5	966C Loader Caterpiller	99	130 hp
6	D4D Bulldozer Caterpiller	98.5	56 hp
7	Monashee - Wagner	98.6	52 hp
8	Service Truck - Wagner	98.6	52 hp
9	Development Jumbo-Wagner	98.6	52 hp
	Logarithmic Average	100.54	

propel vehicles, there is a need to make noise and vibration from diesel engines more acceptable, apart from the requirements to reduce overall levels to bring the total vehicle noise below limits submitted in legislation. The worker must see and hear everything, so that he may work undisturbed and escape dangerous conditions.

REGULATIONS AND STANDARDS

Proposed new CSA Standard Z107.32, Test Procedure for the Determination of Exterior and From Construction, Forest and Mining Machines, has been introduced. This test procedure was written specifically to provide a Canadian test procedure which harmonizes with the intent of the EEC (Common Market) procedure contained in the Official Journal of European Communities (Ref. document EEC 79/113), International Organization for Standardization documents ISO 4872 and ISO/DIS 6393, and SAEJ919 SEP 80 - Sound Measurement - Earthmoving Machinery - Operator - Singular Type.

The EEC and ISO documents basically converted ISO 4872-1978 into a sound power test procedure for earthmoving machines, to be adopted by all EEC member countries. Some experts wanted the procedure to be of the complexity of conducting dynamic tests, dynamic "sound power" tests have been held in abeyance.

This proposed CSA document covers a broader range of construction, forestry and mining machinery because Canadian export. The mining machine industry and research have to support development and create a positive environment for advancement to provide solutions to our most pressing problems: to become effective, economical and environmentally acceptable, and more competitive in world market(2).

For the operator sound this test procedure has been cross-referenced to SAEJ919 SEP 80 - Sound Measurement - Earthmoving Machinery - Operator -

Singular Type. The SAEJ919 SEP 80 was endorsed for use in Canada by the working group and sub-committee.

The regulations presently used in Canada, excepting British Columbia, are those adopted by the OSHA, for example, which permit a worker to be exposed to a noise level of 90 dBA for 8 h/day and require dividing in half the permissible exposure time for each 5 dBA increase in noise level. British Columbia has an exchange rate of 3 dB increase for halving of duration (ISO R 1999).

Table 2 shows the existing, future and possible long-term limits for vehicles in Western European Countries, and Table 3 shows the same information for North America.

NOISE AND VIBRATION BY DIESEL ENGINES

Noise is radiated from external surfaces of the engine as they vibrate in response to the forces developed within the engine. Figure 1 summarizes the structure response of the engine in terms of those parts which respond most strongly to the various exciting forces (Lucas CAV Limited).

Most of the noise radiated by the engine surfaces originates from:

1) Combustion noise: compression, combustion and expansion pressure transients developed in the cylinder. The combustion noise was studied in detail by Priede (3, 4);
2) Piston slap: impacts between piston and cylinder wall, as the piston moves from side-to-side during the engine cycle. Piston slap has been studied by several groups of research workers (5 to 11);
3) Timing gear impacts: impacts between timing gear teeth, as backlash is taken up in either direction in response to crankshaft torsional vibration and the fluctuating torque requirements of the camshaft and the fuel injection equipment (12).

Table 2 - Noise limits proposed for west European countries.
Test modified R362 (R177 or similar) at 7.5 meters.

Category	Maximum Permissible Noise Level in dB(A) at 7.5 m		
	(Now)	After Oct. 1982 EEC Directive 212	After Oct. 1985/8 (Future Possible)
Truck > 3.5 Mg < 149 kW	89	86	(80)
Truck > 149 kW	91	88	(80)

Table 3 - Noise limits proposed for USA (test J366b) at 50 ft.

Category	Maximum Permissible Noise Level in dB(A) at 15.23 m		
	1980 (Now)	After 1982 (Future Definite)	After 1985 (Future Possible)
Medium and Heavy trucks > 10,000 16 GVW at 50 ft. (test J366B)	83	80 (Jan. 1, 1982)	(75?)
Buses at 50 ft. (test J366b)	83	80 (Jan. 1, 1983)	77
Buses Interior Noise (Noisiest Position)	86	83 (Jan. 1, 1983)	80

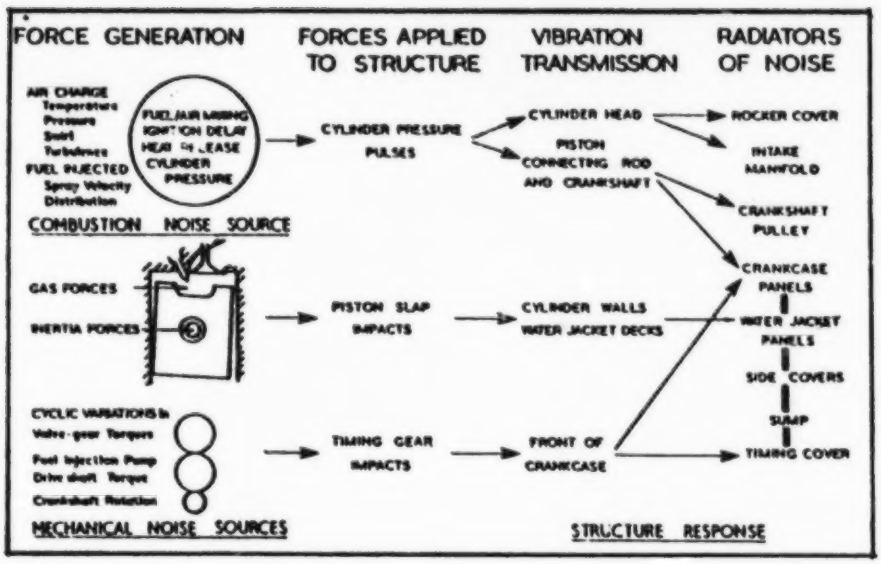

Fig. 1 - Noise and vibration from diesel engines (Lucas CAV Limited)

Vibration measurements will be made at a grid of accelerometer positions on the engine surface and at operator's seat.

Tyre noise has been studied all over the world with the object of reaching an understanding of the mechanism of tyre noise and of specifying a tyre design for the quite heavy vehicle which would meet the target noise level of 77 dBA.

All measurements will be performed in laboratory (indoors and out doors) and underground in mines.

LABORATORY MEASUREMENT

INDOORS

The measurement method of engine noise should be as reliable and as simple as possible, consistent with giving results which are representative of the noise emission properties of engines.

The existing procedures for rating the noise emitted by engines are in numerous national and international noise measurement procedures (13 to 17). The results obtained vary significantly with procedure used, and not all procedures offer the means for determining sound power.

Measurements on 3 metre radius hemisphere and at 1 metre (front, top and two sides) are recommended. From both methods, sound power can be determined simply and with good accuracy (Fig. 2)(18).

Calculation of Sound Power Level and Directivity Index from microphones positioned on the surface of a 3 metre radius hemisphere is as follows:

$$SWL = SPL_A + 10 \log_{10} 2\pi r^2 \text{ (dB)} \qquad \text{Eq 1}$$

where, SWL = Sound Power Level (dBre 1pW)

SPL_A = Average Sound Pressure Level (dBre 20 μPa)

$$= 10 \log_{10} \frac{1}{n} \left(\text{antilog}_{10} \frac{SPL_1}{10} + \text{---} \text{ antilog}_{10} \frac{SPL_n}{10}\right)$$

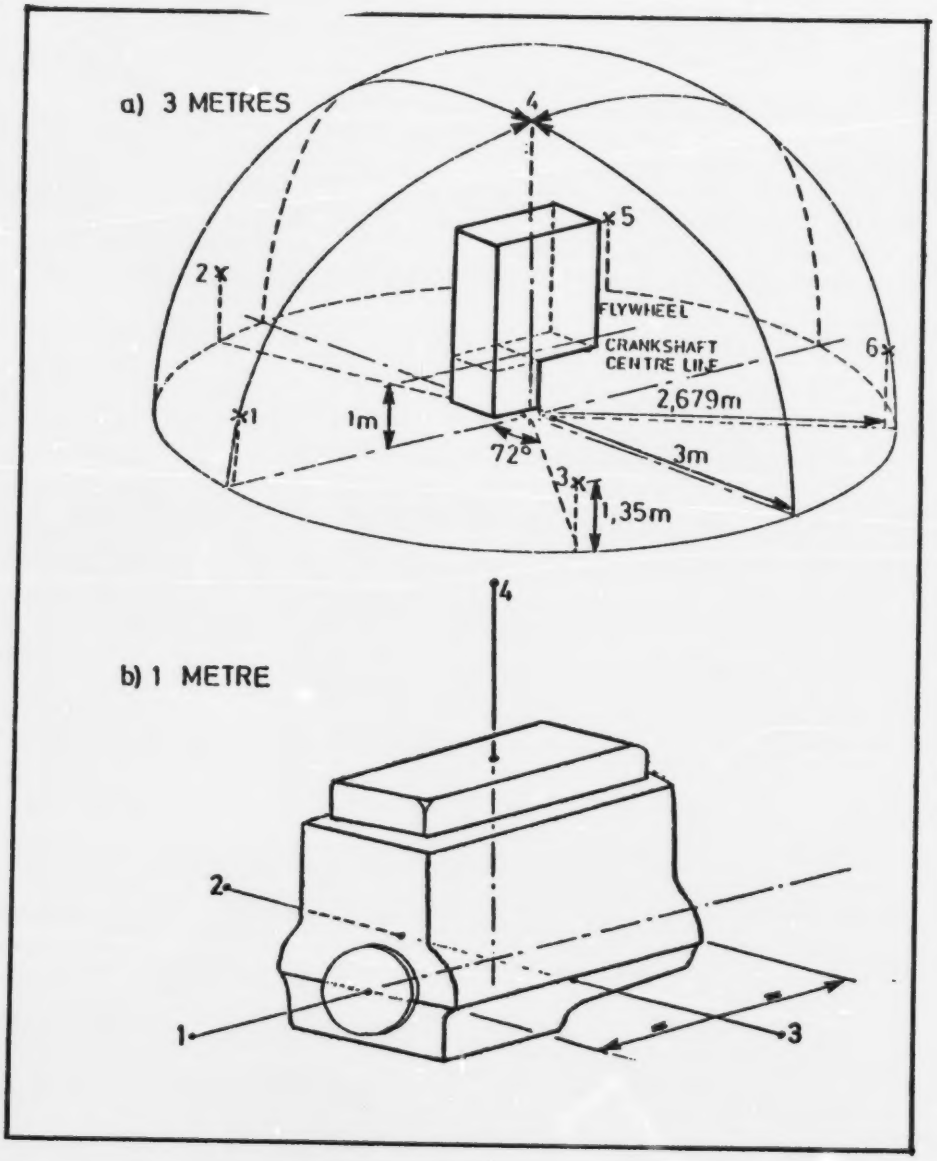

Fig. 2 - Microphone positions.

n = number of microphones

r = radius of hemisphere (m)

when, r = 3 meters

$SWL = SPL_A + 17.5$ (dB)

(see development in reference 18)

and at 1 m measurements, the sound power level of an engine is given by adding 12.1 dB:

SWL = Average SPL at 1 m + 12.1 (dB) Eq 2

The single figure rating is useful for comparing with intensity measurements and sound power from vibration measurements.

For sound (noise) measurement CANMET's instruments will be used and for vibration measurement Portable Vibrating Analyzer Type 3513 should be used (Fig. 3). The instrument is completed self-contained and intended for machine condition monitoring and the general study of mechanical vibration. The Vibration Meter measures displacement, velocity or acceleration in RMS or peak-to-peak values to conform to a variety of established machine vibration criteria. It can be set to the 10 to 1000 Hz frequency range for monitoring vibration severity in accordance with ISO national and industry standards. The tunable filter enables frequency analyses range 03 Hz to 15 kHz, and frequency analysis with wide and narrow band filter. Synchronization for semi-automatic frequency response plotting on CANMET's level recorder can be done.

Investment is: (duty included)

3513 Portable Vibration Analyzer 2511 Vibration meter 1621 Filter 4370 Accelerometer	$ 9,183.00
4370 Accelerometer	797.00
A00087 Cables	23.00
AQ0034 Cables to 2306 CANMET's Level Recorder	92.00
Casework	215.00
Total:	$10,310.00

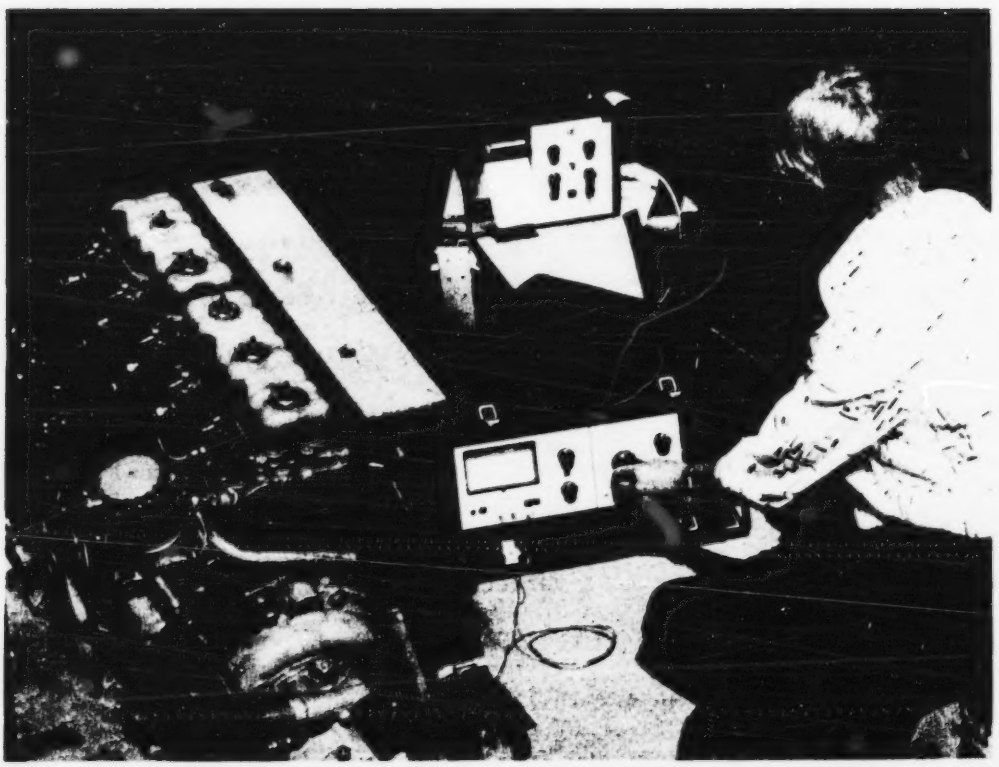

Fig. 3 - Measurement displacement, velocity or acceleration or peak-to-peak values on engine.

OUTDOORS

In this measurement, an important objective was the evaluation of the additional costs of quieting the final demonstration vehicle and the establishment of the variation in cost for various degrees of quieting.

Uniform test procedures are a key element in this measurement. Standard CSA sound level test procedures Z107.32 must be applied. The standard is proposed and specifies procedures for determining representative A-weighted sound levels exterior to the machine and in the operator's station. The microphone shall be positioned to coincide with the surface of a hemisphere enclosing the machine (Fig. 4). The radius of the hemisphere shall be determined by the machine length. All instruments for outdoor measurements are identical with underground measurements. In this study standards should be applied from references 19 to 34, only in the special cases.

UNDERGROUND MEASUREMENT

This is a fully automated system designed for seven days to retrieve sound pressure information from 3 channels and vibration information from 5 channels in an underground environment on mining vehicles (Fig. 5). Power is to be provided by one or more automobile batteries, and data is stored on a cassette tape in digital form, thus reducing the possibility of data loss through power drop-out.

SOUND (NOISE)

The purpose of this equipment is to correlate vehicle noise with noise dose to operator. This figure relates to operator fatigue and hearing loss. Further information will be gathered which will aid in reaching the noise target for the vehicle.

Sound pressure levels will be measured at 3 locations using type 4165

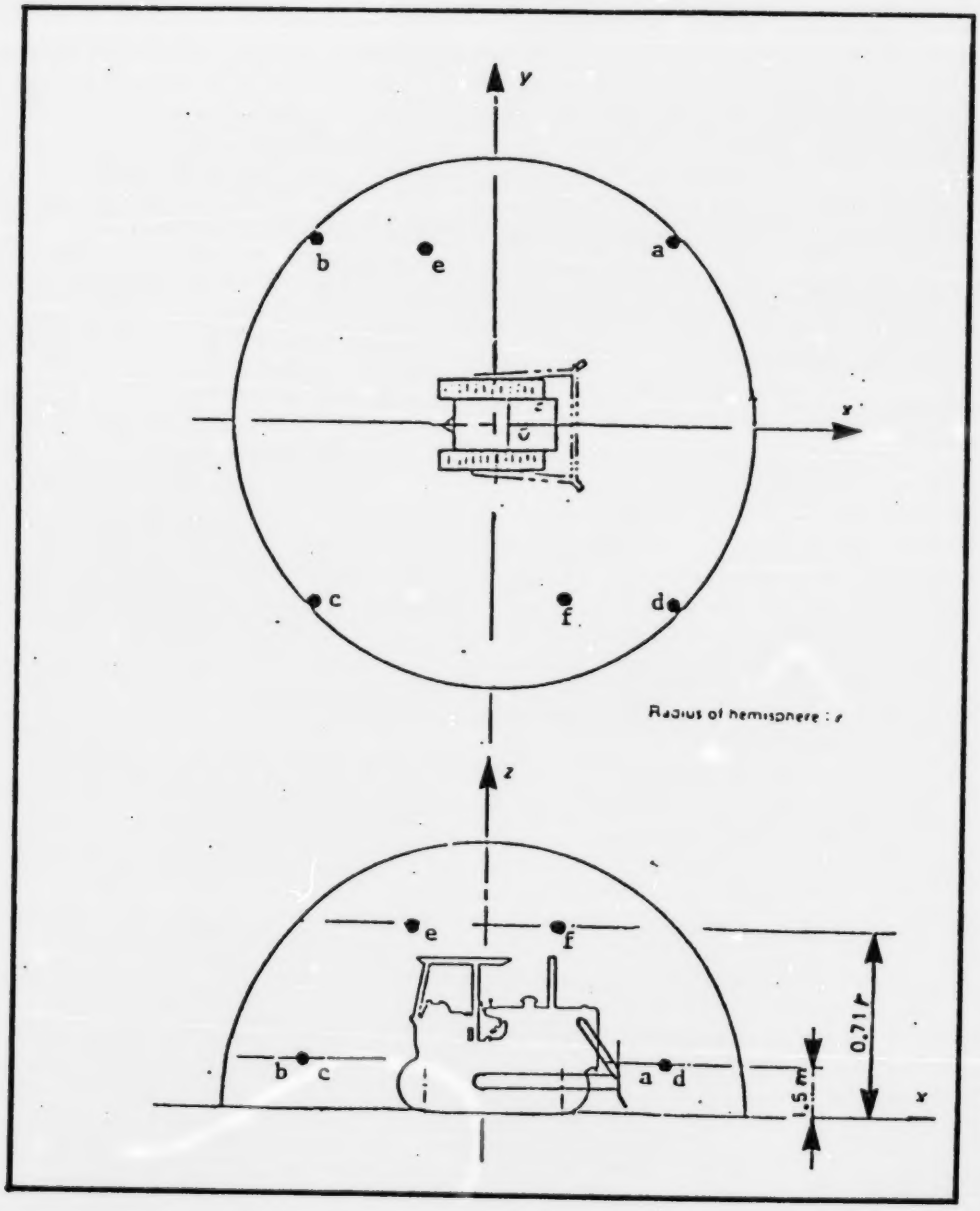

Fig. 4 - Microphone array on the hemisphere.

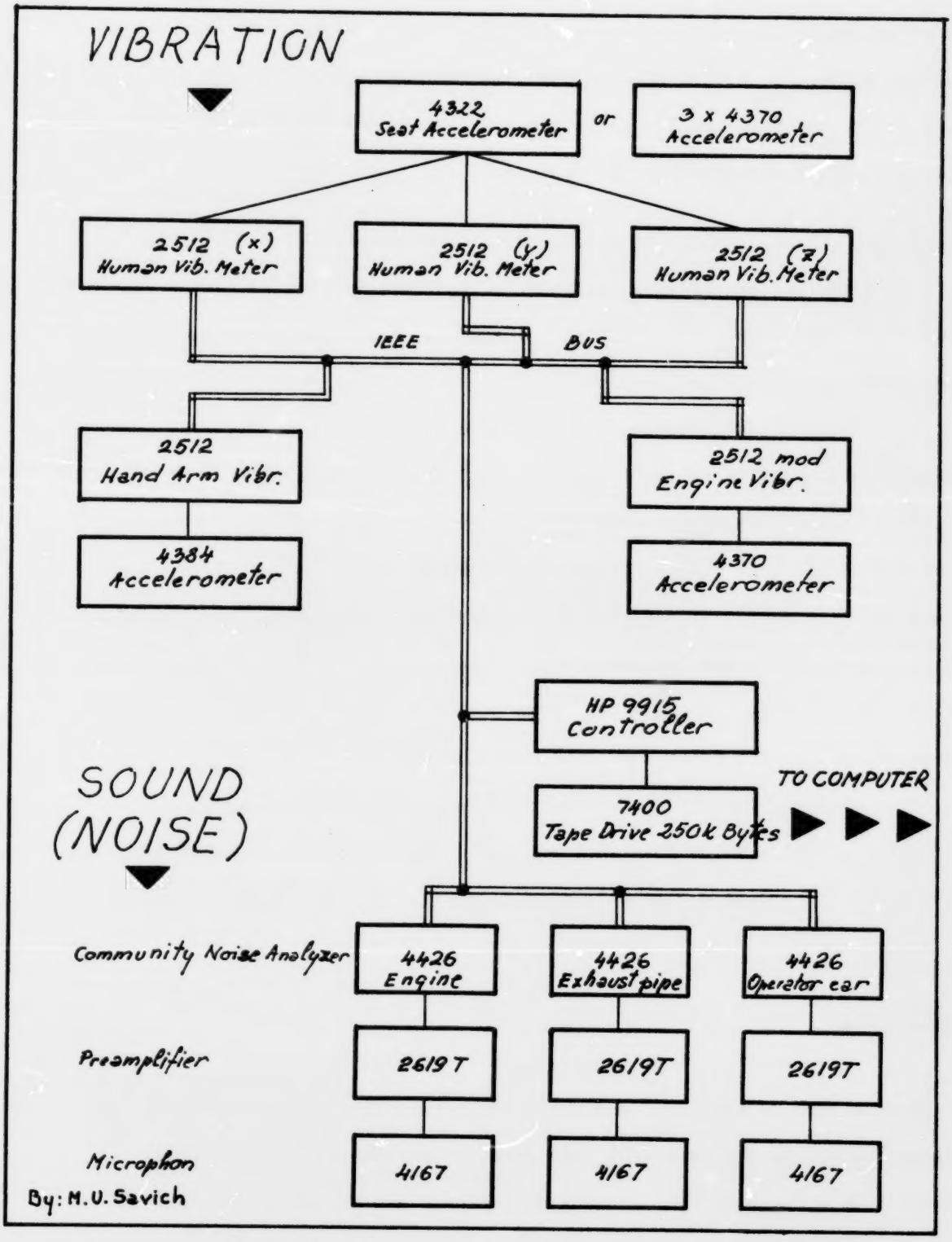

Fig. 5 - Sound (noise) and vibration measurements on a mining vehicle.

microphones in conjunction with type 2619 preamplifiers. The locations should be on the engine, at the exhaust pipe, and at the operator's ear. Special cabling may be required for this last application. All measurements will be made in dBA, a universally accepted unit.

VIBRATION

The purpose of this equipment is to correlate engine-vehicle vibration with whole body vibration dose to the operator. This dose relates to motion including discomfort and illness.

Whole body information is gathered via a type 4322 Triaxial Seat Accelerometer and is fed to three type 2512 Human Vibration Meters to provide X, Y and Z whole body vibration L_{eg} information. If sensitivity becomes a concern, three type 4370 accelerometers will be used in place of the type 4322. Hand-arm information is gathered by a type 4384 accelerometer and fed to a single type 2512 Human Vibration Meter operating in the hand-arm mode, thus giving Hand Arm L_{eg} information. Both the hand, arm and whole body measurements will be carried-out using ISO compliant equipment.

Engine vibration information will be collected by a single type 4370 and the L_{eg} calculation furnished by a type 2512 specially modified by Bruel and Kjaer to include a flat weighting curve with the appropriate frequency cut off.

CONTROLLER

The system will be controlled by an HP9915 or similar. This controller will pole each of the sound and vibration meters once every 60 seconds, and store the L_{eg} in the type 7400 tape drive. This program will be burnt into PROMs thus eliminating the loading of software and automatic hook-up will be eliminated. Program selection shall be via push-button control with readily

accessable RESET,START and PAUSE controls. Provision will be made for the loading of data into a Senturian Series 200 Status Reporting and Control System computer from the type 7400 tape drive.

HOUSING OF EQUIPMENT

The equipment shall be mounted in a NEMA 12 enclosure suitable for placement on a mining vehicle. Elliot Lake Laboratory in cooperation with Bruel and Kjaer will determine the appropriate shape, size and mounting procedure for this item.

INVESTMENT

	Each	Duty Included Total
For sound (noise):		
3 x 4426 Community Noise Analyzer	$8,319.	$24,957.
3 x 2619T Preamplifier	590.	1,770.
3 x A0028 (if required) Extension Cable	447.	1,340.
3 x 4165 Microphone	721.	2,163.
3 x UA0393 Rain Cover (if required)	612.	1,836.
		32,047.
For vibration:		
5 x 2512 Human Vibration Meter	7,739.	38,695.
1 x 4322 Triaxial Seat Accelerometer		2,034.
4 x 4370 Accelerometer (high sensitivity for set)	797.	3,188.
1 x 4384 Hand/Arm Accelerometer		782.
(Also required - accelerometer cable)*		
		44,699.
For sound (noise) and vibration:		
9915 Controller		5,000.*
2 x 7400 Tape drive	7,509.	15,018.
Programming + ROMS		5,000.
10 x A00129 Interfan cables	326.	3,260.
Modification of 2512 for engine vibration		2,000.*
Packaging for underground environment and batteries		5,000.*
		35,278.
Grand Total:		$112,024.

*These items are estimated in firm quotation and will be provided.

CONCLUSION

The major contributors to the high noise level of underground mines by diesel-powered equipment were identified as load-haul-dump machines and ore trucks.

Most difficult problem is to reduce the engine surface noise. The engine noise requires a reduction of more than 10 dBA, to meet OSHA requirement. The noise and vibration are in causal connection.

In general there are three basic ways to reduce combusion noise:

- reduce ignition delay period;
- reduce fuel injected in the ignition delay period; and
- restrict air/fuel mixing during the delay period.

Any changes made to combustion system to reduce noise will affect other aspects of combustion system performance: smoke, fuel consumption and emissions of nitrogen oxides and unburnt hydrocarbons. The research will be very difficult. Total investment in noise and vibration instruments is $122,334.00.

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